Constraints on precipitation microphysics from cold-season ground validation observations

Norman Wood
Claire Pettersen

University of Wisconsin - Madison
Space Science and Engineering Center

Acknowledgements: Mark Kulie, Tristan L'Ecuyer, UW; Andy Heymsfield, NCAR; Peter Rodriguez and Dave Hudak, EC; Larry Bliven, NASA GSFC; Gwo-Jong Huang, CSU; Frederick Fabry, McGill

Outline

- Microphysics from GV instrument suites, surface observations
- Microphysics aloft, aircraft-based
- Linking surface and aircraft observations with a blended retrieval for microphysics
- Connecting precipitation regimes to microphysical properties (Claire's poster 248)
- Status and plans

Microphysical properties and size distribution underlie Z_e and P

$$P = \frac{1}{\rho_{liq}} \int N(D) m(D) V_t(D) dD$$

$$m \approx \alpha D_M^{\beta}$$

$$A_p \approx \gamma D_M^{\sigma}$$

$V_t(D)$ { mass, A_p, (shape, orientation), $T_i, p_i, \cdots$

{ mass, shape, orientation, phase, ... } $\sigma_{bk}(D)$, $\sigma_{ext}(D)$

$$Ze = \frac{\Lambda^4}{\|K_w\|^2 \pi^5} \mathcal{T}_{0,R}^2 \int N(D) \sigma_{bk}(D) dD$$

$P(Z_e)$ uncertainties:

- **Unknown particle properties and N(D)**
- For P, other fallspeed parameters, updrafts
- For Z_e, multiple scattering, beam filling
- Discretization, truncation

What about existing observations of mass and A_p?

$$m \approx \alpha D_M^{\beta}$$

$$A_p \approx \gamma D_M^{\sigma}$$

Traditional Methods

Single-particle:

- **Mass:** Volume and density
  Melted drop diameter
- **Area:** Particle image measurement (photomicrographs, 2D probe images)

Bulk:

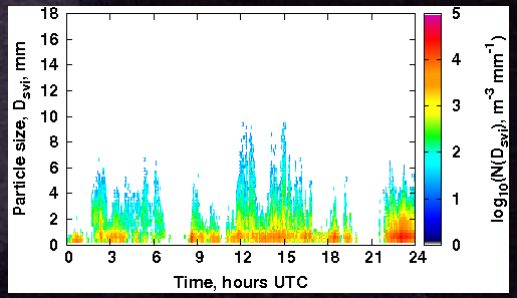
- **Mass:** N(D) with integral constraint (IWC, ∑P, Ze)

Limitations:

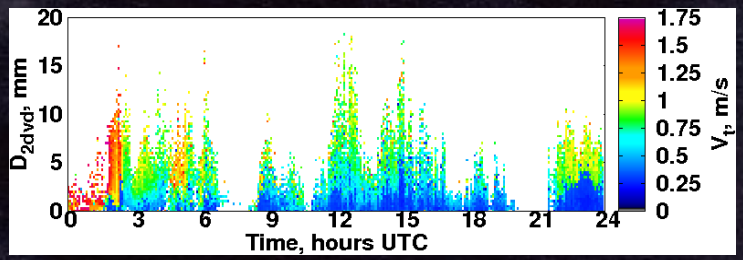
- Sampling (locations and sample sizes)
- Characterization of uncertainties
- Consistency
- Covariance information

Multi-sensor GV obs constrain particle properties, enhance sampling

$$m \approx \alpha D_M^{\beta}$$
$$A_p \approx \gamma D_M^{\sigma}$$

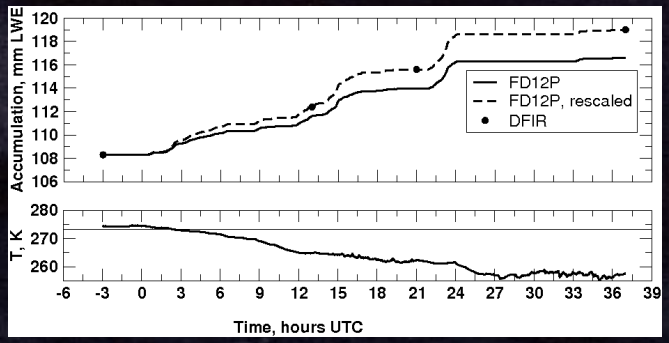


Size distribution N(D)



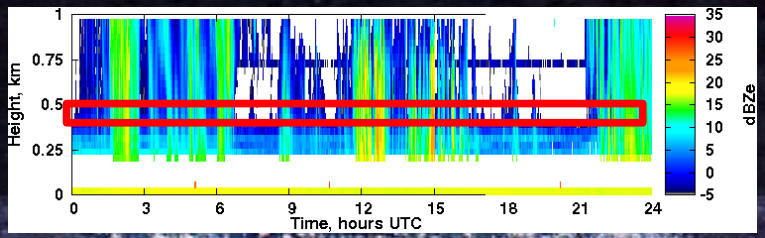
Size-resolved fallspeeds

$$V_t(D) = V_t\left(D, \frac{\alpha}{\gamma}, \beta - \sigma, \cdots\right)$$



Precipitation rate

$$P = \frac{1}{\rho_{liq}} \int N(D)\alpha D^{\beta} V_t\left(D, \frac{\alpha}{\gamma}, \beta - \sigma, \cdots\right) dD$$



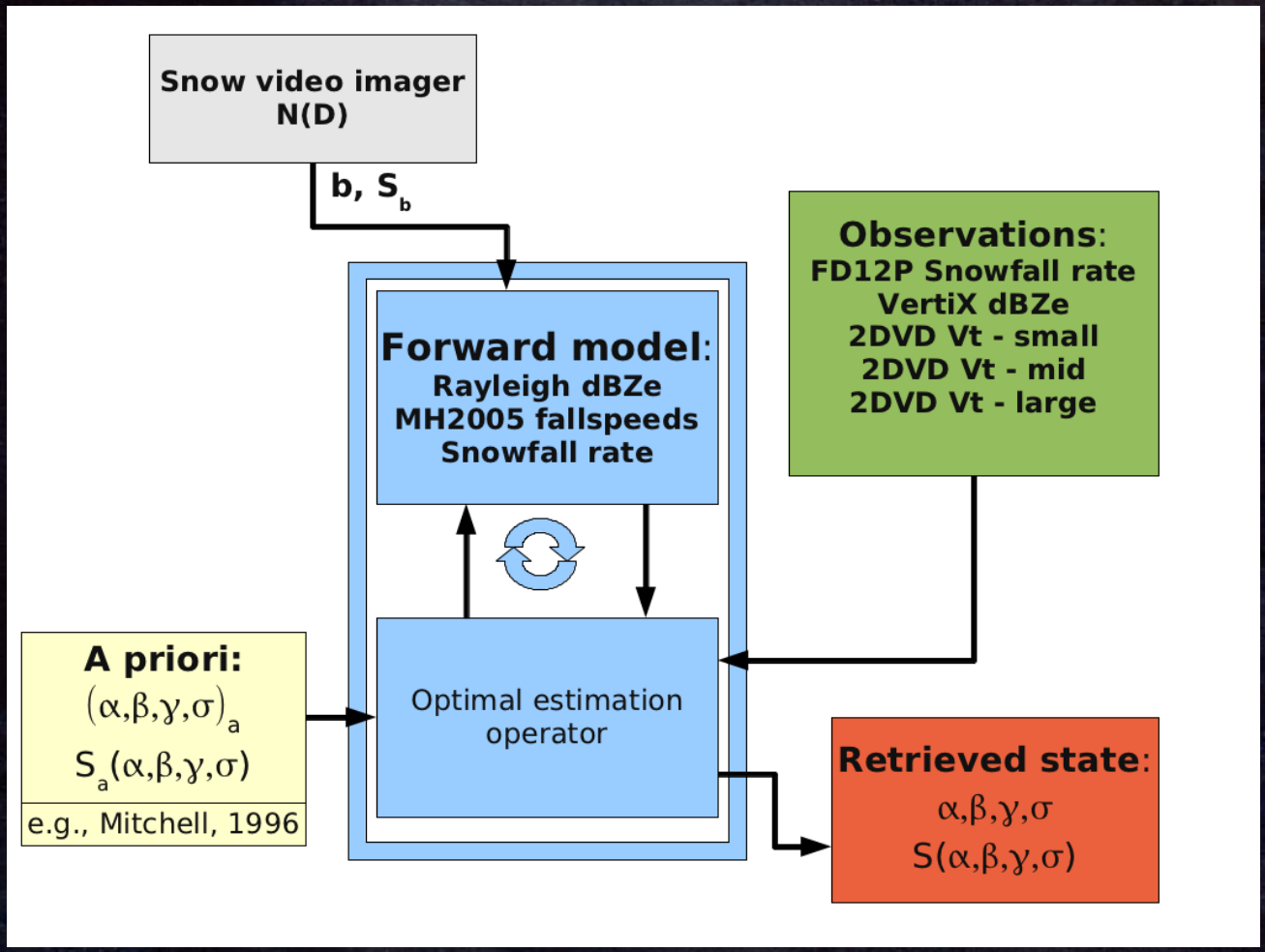
Rayleigh-regime reflectivity

$$Ze = \frac{36}{\pi^2 \rho_{ice}^2} \frac{\|K_i\|^2}{\|K_w\|^2} \alpha^2 \int N(D) D^{2\beta} dD$$

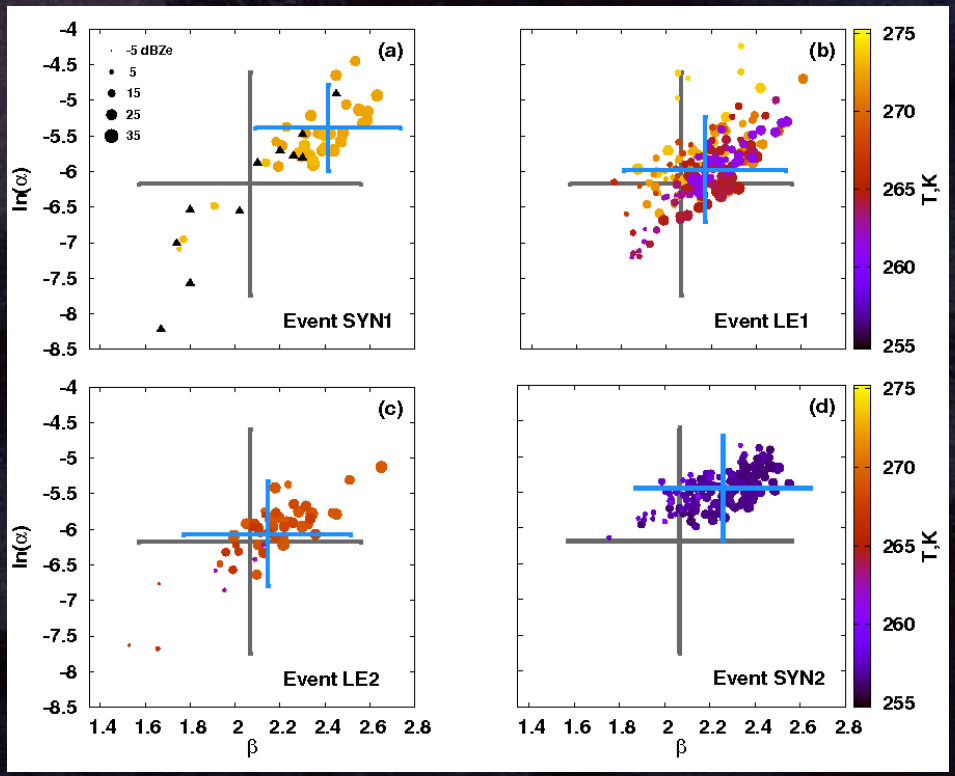
Optimal estimation applied to VertiX, FD12P, 2DVD, and PIP observations

$$m \approx \alpha D_M^{\beta}$$

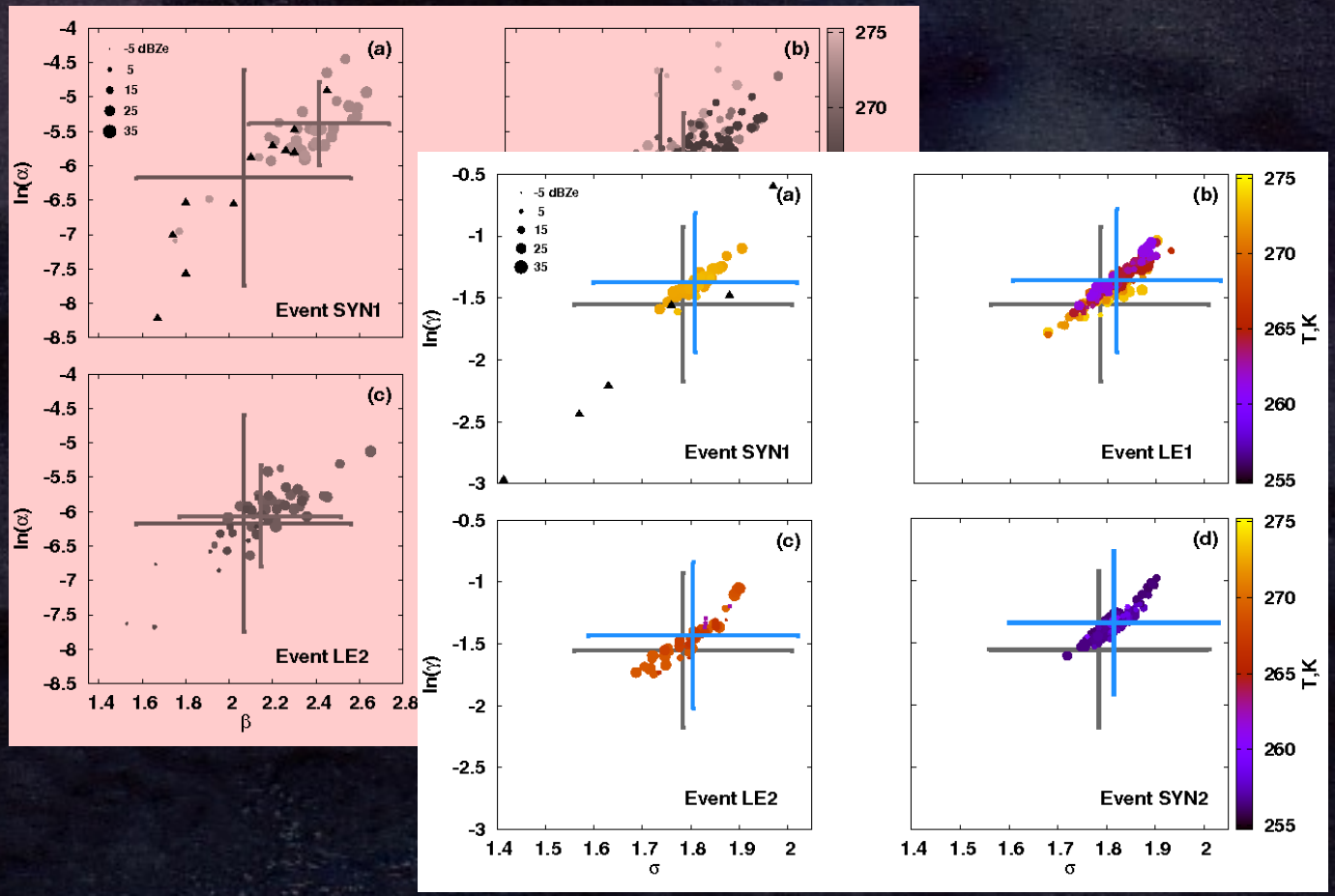
$$A_p \approx \gamma D_M^{\sigma}$$



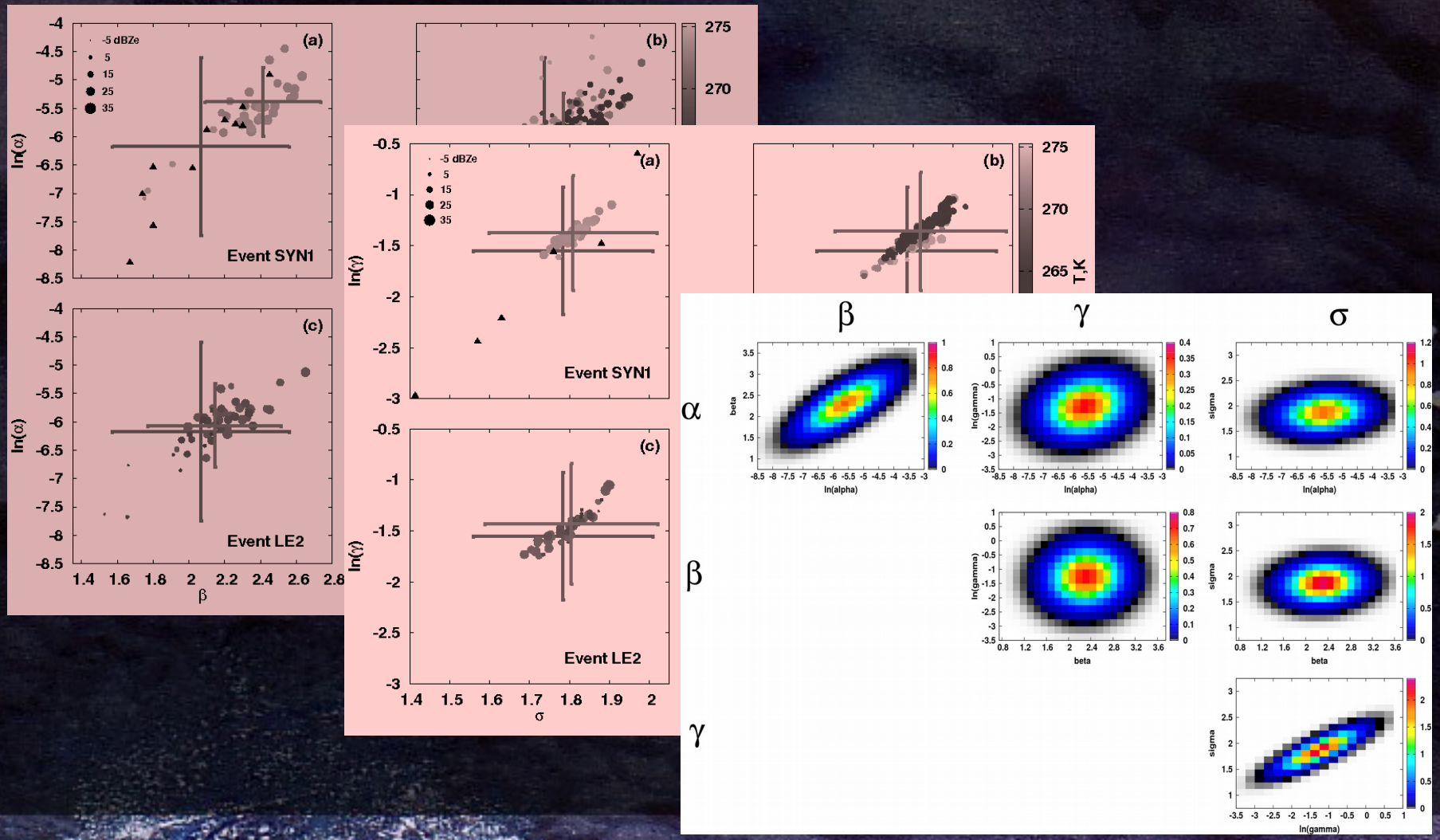
Retrieval shows some skill for constraining mass parameters...



Retrieval shows some skill for constraining mass parameters, less skill for area...



Retrieval shows some skill for constraining mass parameters, less skill for area, and gives covariances



Information content responds to uncertainties in observations and forward models

		A matrix diagonals			
H	d_s	ln(alpha)	beta	ln(gamma)	sigma
3.07	1.83	1.01	0.28	0.33	0.09

How would improvements affect retrieval performance?

- **Ze:** clean near-surface measurement
- **P:** replicate observations
- **N(D):** increased sample volume
- **Vt:** reduced forward model errors

	Standard	Ze	P	N(D)	Fallspeed
H	3.07	3.86	3.87	3.90	4.80
d_s	1.83	1.89	1.90	1.90	2.32

Microphysics aloft from in-situ aircraft observations

Aircraft in situ sampling aloft

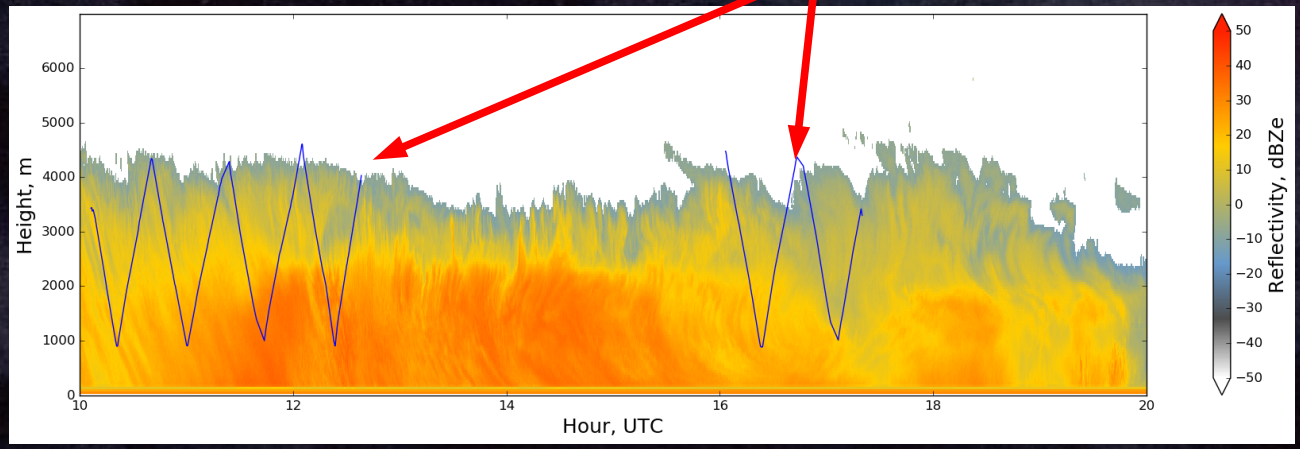
- N(D): 2D probes
- A_p(D): 2D probes
- WC: King, Nevzerov, CVI

Benefits

- Reduced ambiguity in D
- Vertical sampling

GCPEx VertiX at CARE

UND Citation



Interposing radar observations

- Ze(h)
- V_{dop}(h)

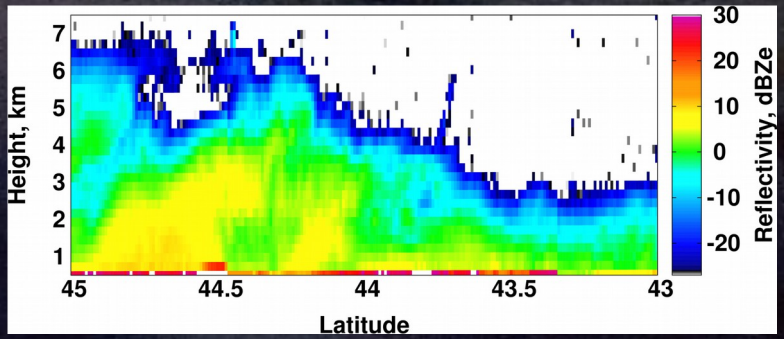
Surface observations

- N(D)
- V_t(D)
- P
- Z_e(0)

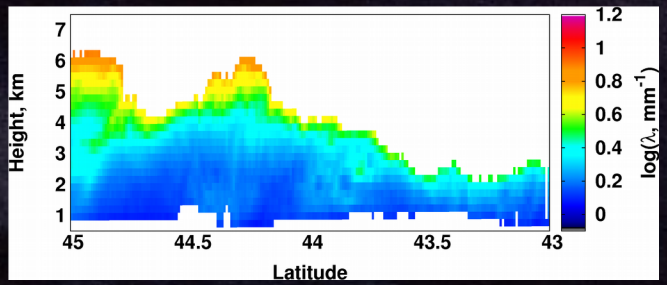
What do we do in between?

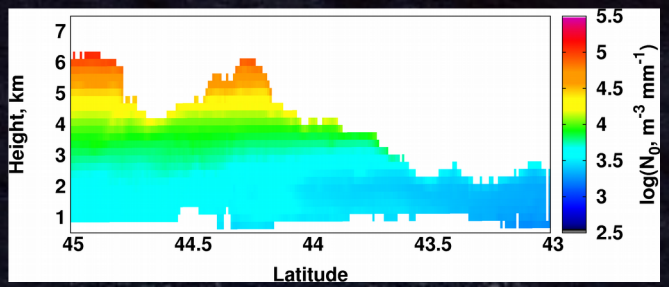
Radar-only: Requires assumptions about particle microphysical properties, scattering properties, size distribution

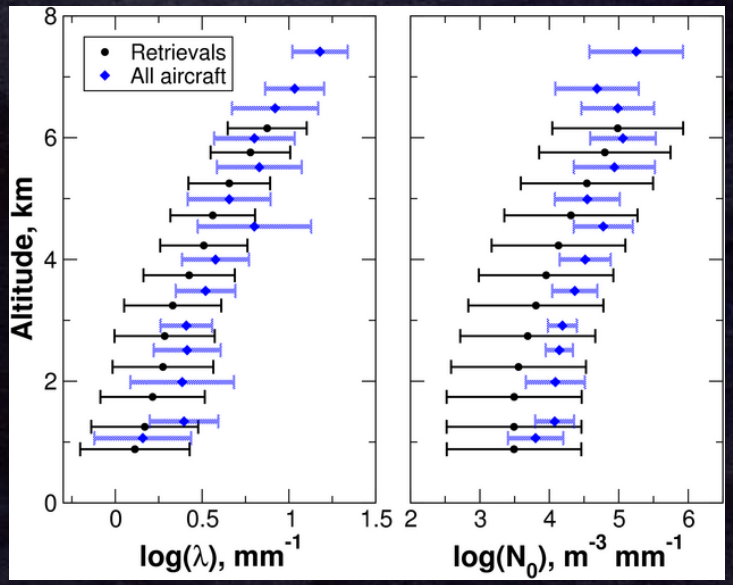
$$N(D) = N_0 \exp(-\lambda D)$$



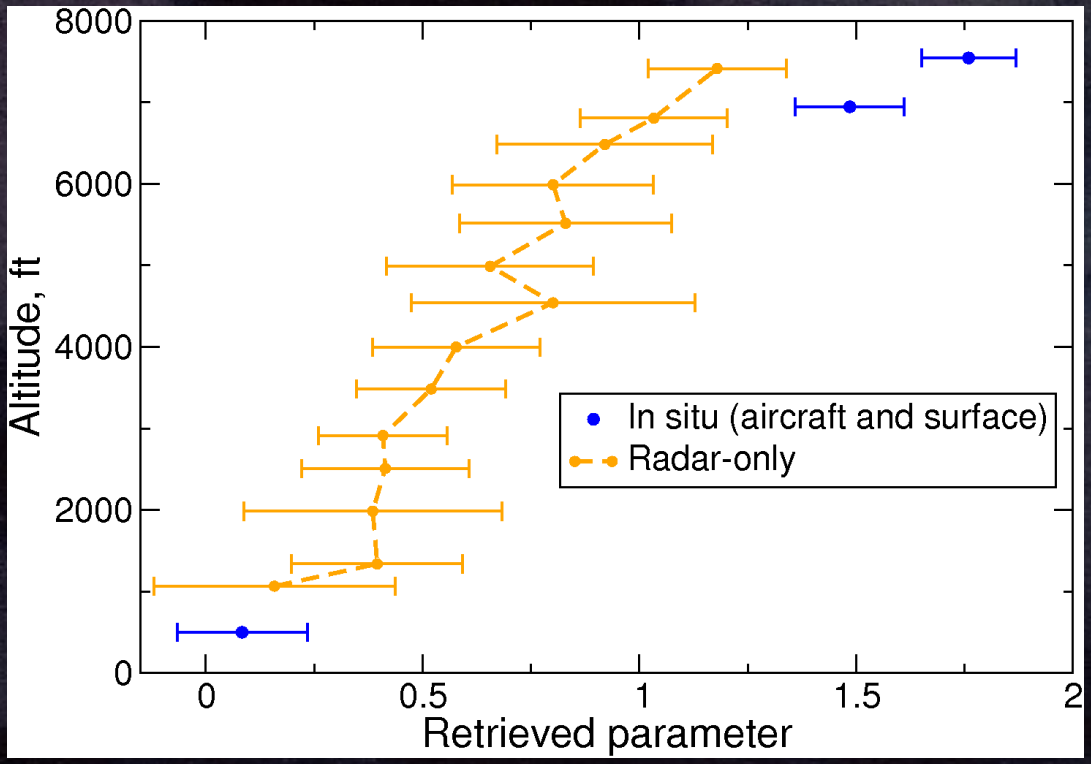
OE implementation retrieves Gaussian probability distribution functions for size distribution parameters.



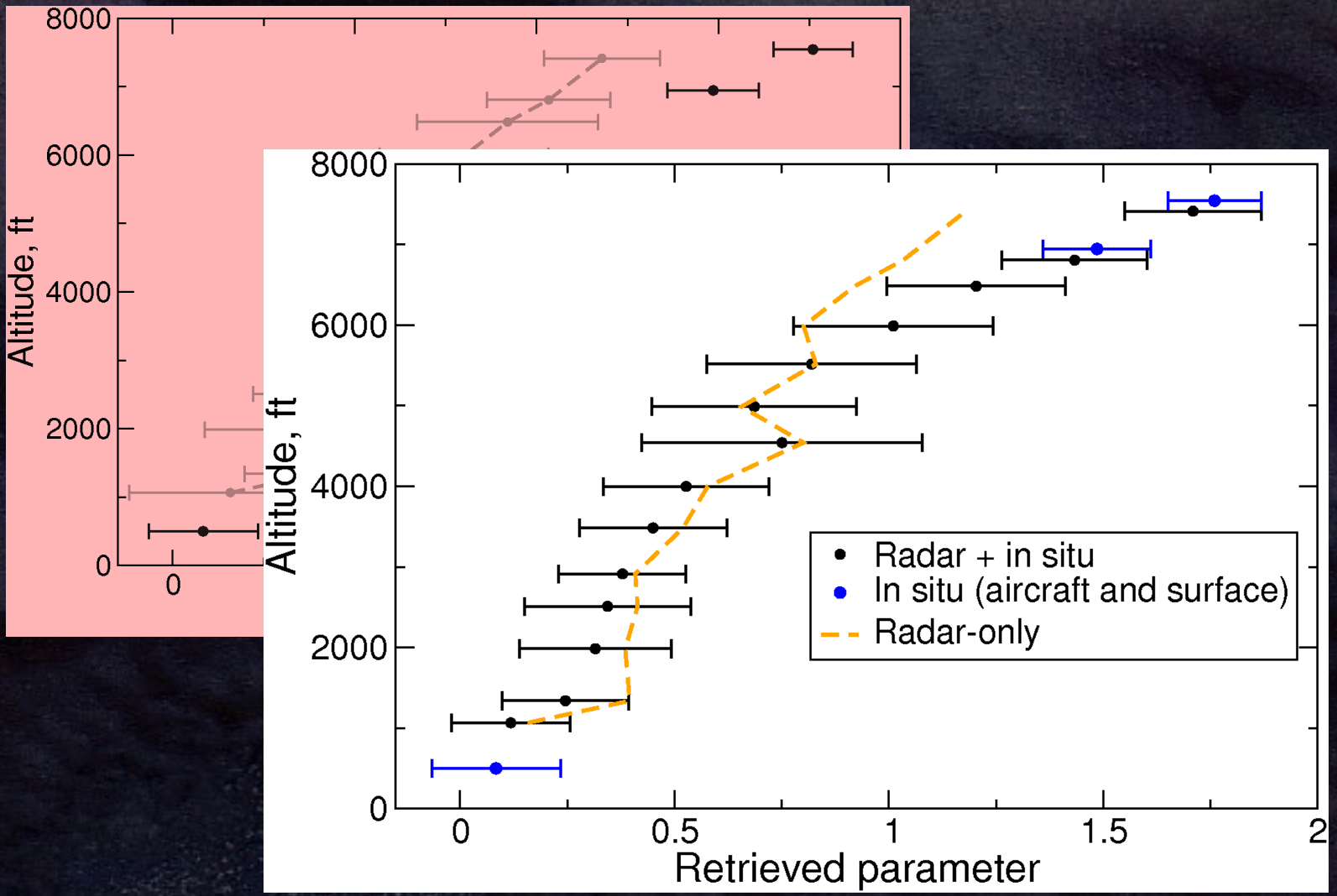




Schematic retrieval result



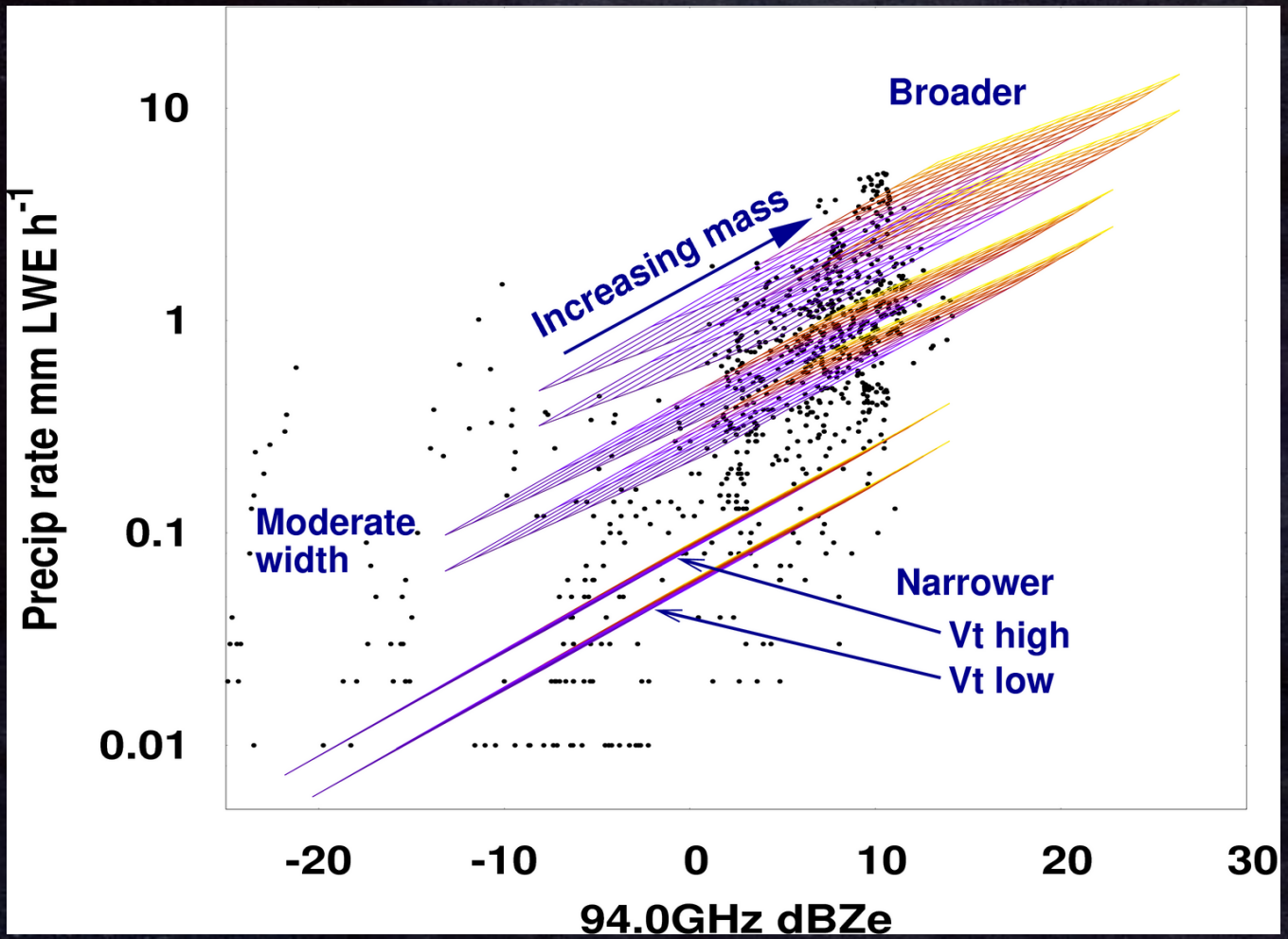
Schematic retrieval result



Status/plans

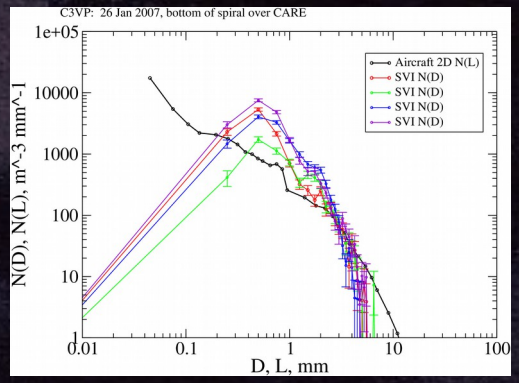
- Forward models: Development for V_{dop}, WC and Z_e (MRR) to complete sensitivity and uncertainty assessments.
- Precip event observations: Cases ID'd and data collection for GCPEx. Radar-based regime classifications (see poster 248) done. Modest collocation/resampling and uncertainty modelling to do.
- Synthetic testing. Beginning after forward model development is completed. Test datasets derived from earlier work.

Uncertain microphysics contributes significant uncertainty to Z_e



Influence of D_{obs} on microphysics retrieval

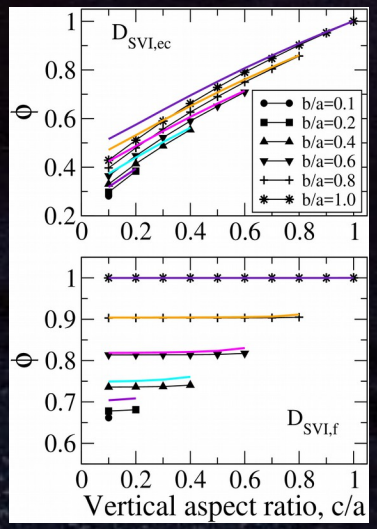
2D probe compared to SVI

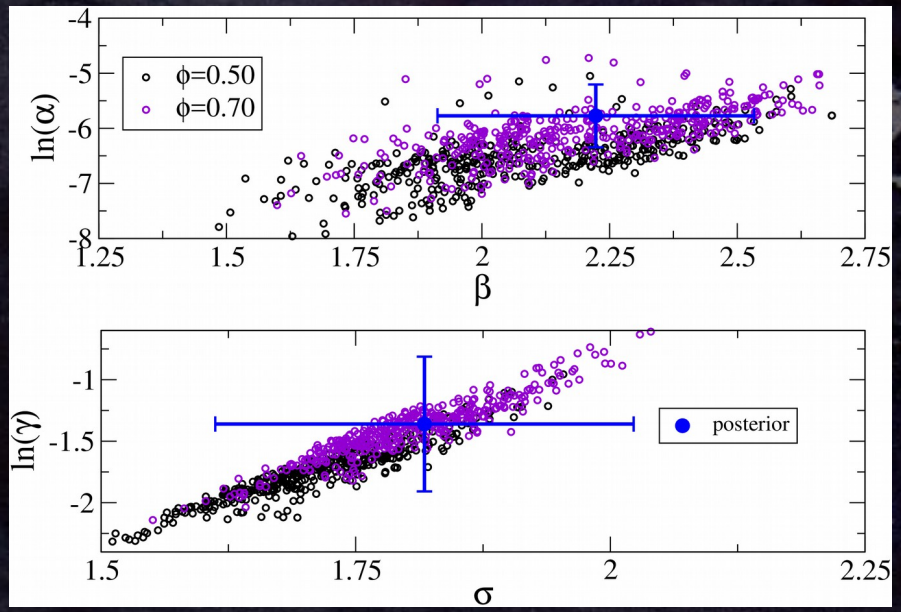


$$D_M = D_{obs}/\phi$$

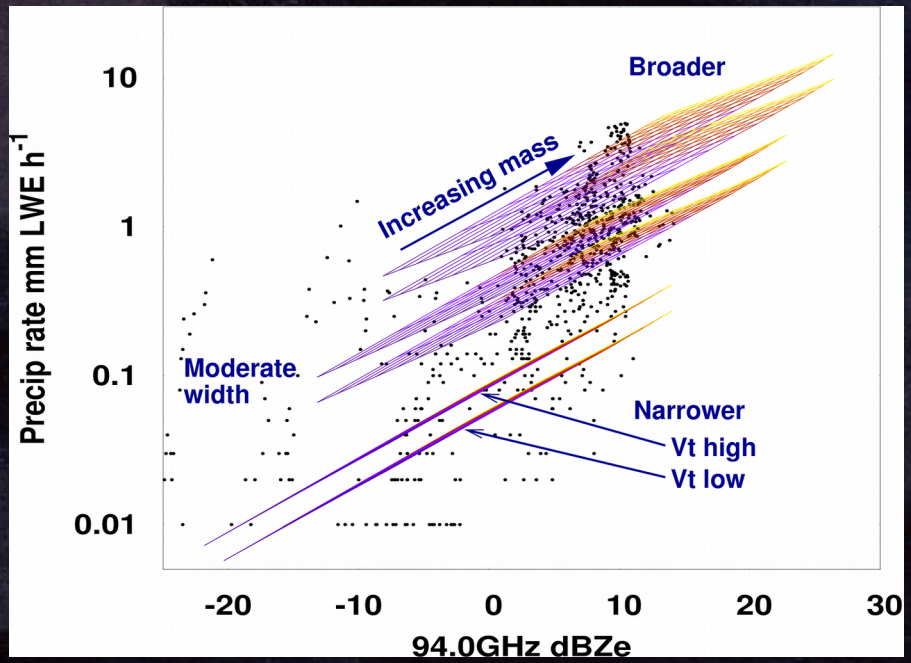
$$N(D_M) = N(D_{obs})\frac{\partial D_{obs}}{\partial D_M} = N(D_{obs})\phi$$

Modeling with ellipsoids

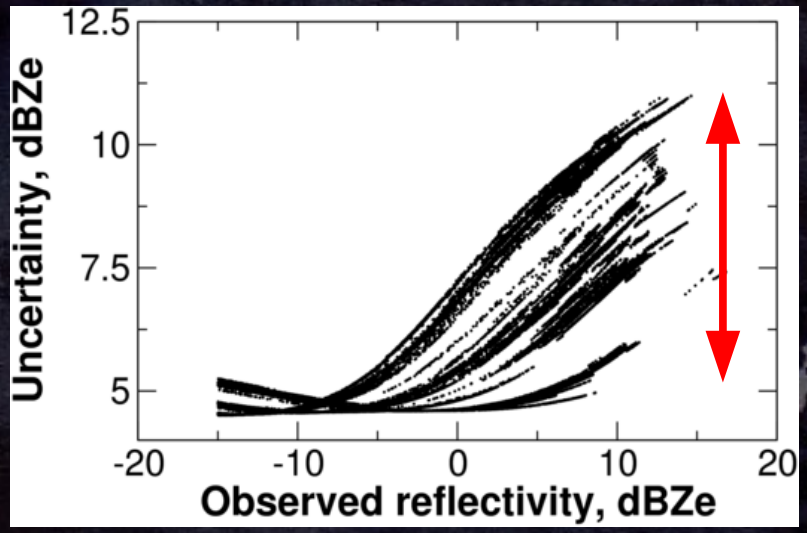




Uncertain microphysics contributes significant uncertainty to Z_e



Uncertainties related to particle mass m(D), projected area A_p(D) (W-band example)



Source	Uncertainty
Disc. & Trunc.	0.4 dBZe
Shape	2. dBZe
Exp. dist.	< 1. dBZe
Measurement	< 0.5 dBZe